Use of Dual-Wavelength Radar for Snow Parameter Estimates

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ABSTRACT

Use of dual-wavelength radar, with properly chosen wavelengths, will significantly lessen the ambiguities in the retrieval of microphysical properties of hydrometeors. In this paper, a dual-wavelength algorithm is described to estimate the characteristic parameters of the snow size distributions. An analysis of the computational results, made at X and Ka bands (T-39 airborne radar) and at S and X bands (CP-2 ground-based radar), indicates that valid estimates of the median volume diameter of snow particles, D_0, should be possible if one of the two wavelengths of the radar operates in the non-Rayleigh scattering region. However, the accuracy may be affected to some extent if the shape factors of the gamma distribution used for describing the particle distribution are chosen far from the true values or if cloud water attenuation is significant. To examine the validity and accuracy of the dual-wavelength radar algorithms, the algorithms are applied to the data taken from the Convective and Precipitation-Electrification Experiment (CaPE) in 1991, in which the dual-wavelength airborne radar was coordinated with in situ aircraft particle observations and ground-based radar measurements. Having carefully coregistered the data obtained from the different platforms, the airborne radar-derived size distributions are then compared with the in situ measurements and ground-based radar. Good agreement is found for these comparisons despite the uncertainties resulting from mismatches of the sample volumes among the different sensors as well as spatial and temporal offsets.

1. Introduction

Radar has been considered as an effective tool for remotely measuring different types of precipitation. Directly relating a radar measurable, such as the radar reflectivity factor Z to the precipitation rate R, is widely used to monitor and estimate the development of a variety of storms. Sekhon and Srivastava (1970) carefully examined the measured snow size distributions reported by Imai et al. (1955), Magono (1957), and Ohtake (1968), and proposed equations that connect the radar reflectivity to the snow rate in the form of melted water, the median volume diameter, and the liquid water content. Their approach, among others (e.g., Smith 1984; Loffler-Mang and Blahak 2001), uses a single wavelength much larger than the particle sizes so that Rayleigh scattering is appropriate for their analysis. However, in view of the complexity of snow in nature, a single wavelength radar measurement is unable to account fully for the variability arising from different meteorological conditions. As such, it is not surprising to see the existence of many Z–R relations reported in the literatures (see Gunn and Marshall 1958; Carlson and Marshall 1972; Smith 1984; Boucher and Wieler 1985; Matrosov 1992).

Dual-wavelength radar techniques have shown promise in accurately estimating characteristics of the size distribution when one or both wavelengths operate in the non-Rayleigh region (Matrosov 1992, 1998; Meneghini et al. 1992, 1997; Meneghini and Kumagai 1994; Liao et al. 1997; Vivekanandan et al. 2001; Mardiana et al. 2004). A spaceborne radar operating at Ku and Ka bands has been proposed as one of the core instruments for the Global Precipitation Measurements (GPM; Iguchi et al. 2002) and will serve as a calibrator for other instruments aboard the GPM satellite in mapping precipitation globally. With use of dual-wavelength radar, the ambiguities are significantly lessened for the retrieval of the microphysical properties of hydrometeors in comparison with single wavelength radars such as the Tropical Rainfall Measuring Mission (TRMM) precipitation radar (PR; Simpson et al. 1996). In this paper we begin with a discussion of a dual-wavelength algorithm by which the snow particle size distribution can be inferred. In an effort to examine its validity and accuracy, two separate cases from the Convective and Precipitation-Electrification Experi-

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ment (CaPE) in 1991 are studied. The algorithm is applied to measurements taken by a dual-wavelength (X and Ka bands) airborne radar. The retrieved results of the snow particle size distributions are then compared with those from in situ aircraft measurements and the National Center for Atmospheric Research (NCAR) CP-2 S- and X-band ground-based radars that were coordinated with the airborne radar measurements. Good agreement is found for these comparisons despite spatial and temporal offsets as well as the uncertainties resulting from mismatches of the sample volumes among the different sensors.

5. Summary

A description was presented of a dual-wavelength radar algorithm to estimate characteristics of the snow size distribution. For the cases of the airborne T-39 and ground-based CP-2 radars, the computations of the DFR, with respect to the several snow densities and μ, were made as a function of D_0. Analysis of the results indicates that the DFR–D_0 relations for the pair of the X- and Ka-band wavelengths of the T-39 radar are nearly independent of the snow density for most values of D_0, and have only modest sensitivity to the μ parameter of the gamma size distribution. The fact that the DFR depends primarily on D_0 suggests that accurate estimates of the particle size distributions should be possible if the particles are sufficiently large relative to the shorter wavelength and if the attenuation can be either neglected or corrected. Once D_0 is estimated, the N_T can be directly derived from either of the reflectivities at two wavelengths. The N_T, however, depends on the snow density and the assumed μ. This may lead to an error if an inaccurate snow density or μ are used. The results also indicate that the combination of X and Ka bands is far superior in terms of stability and accuracy to the S- and X-band combination for inferring snow characteristics as long as attenuation from cloud water can either be neglected or corrected.

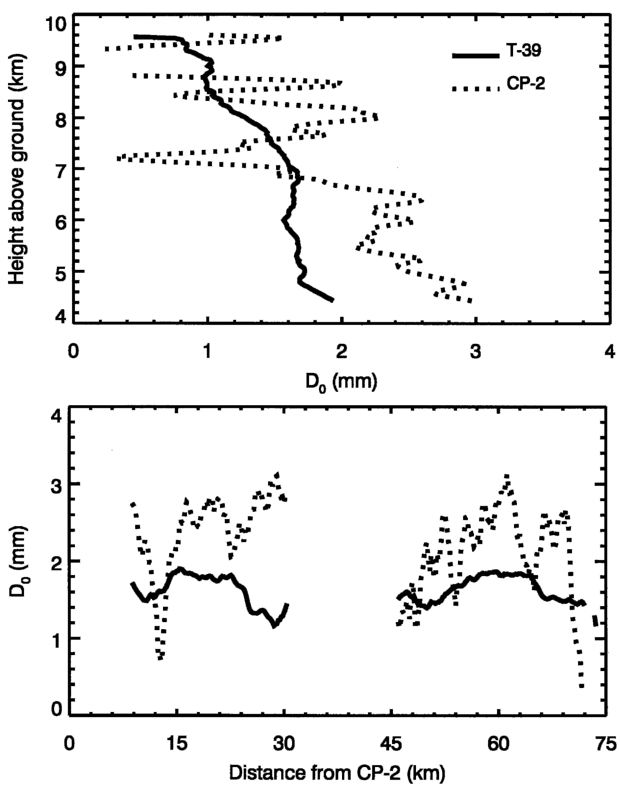

FIG. 15. Comparisons of the (top) vertical and (bottom) horizontal profiles of D_0 as derived from the T-39 airborne and CP-2 ground-based radars in the snow region.

Validation of the dual-wavelength techniques was performed by comparing the derived snow parameters and size distributions from the T-39 airborne radar with direct particle measurements. Having carefully registered the particle information obtained from the aircraft in situ PMS measurements, the radar-derived characteristic snow parameters and size distributions were compared with the measurements. We find that the radar results agree reasonably well with those from the direct measurements by the PMS. Moreover, based on an examination of the PMS 2D images, the signatures of the DFR of the T-39 radar are quite sensitive to the type of the snow particle. From the measurements of the T-39 radar used in our study, the DFR of aggregates appears to be several times greater than that for the graupel. This feature of the DFR, if true for general cases, should help to identify snow type by means of the dual-wavelength radar. Confirmation of this feature requires further study as well as more coordinated radar and particle in situ measurements. It is also found, from the comparisons, that use of the snow densities of 0.2 g cm^{-3} for aggregates and 0.7 g cm^{-3} for graupel for the radar retrieval gives the best agreement. The shape factors of the gamma size distributions are –0.5 for aggregates and 1 for graupel based on the parametric fits of the in situ particle measurements.

To check the consistency of the retrieval, comparisons of D_0 estimates were also made using the T-39 airborne and ground-based CP-2 radars for a stratiform storm from one set of coordinated measurements. Due to the strong fluctuations of the DFR from the CP-2 radar, the comparisons are made only on the mean profiles of the horizontal and vertical measurements of snow above the radar bright band. With the use of the snow density of 0.2 g cm^{-3} and μ of -0.5, it is shown that the retrievals of D_0 from both radars are consistent despite the fluctuations of the results from the CP-2. We conclude that the use of dual-wavelength radar, with properly chosen wavelengths, should provide useful estimates of the microphysical properties of hydrometeors. The GPM precipitation radar, operating at frequencies of Ku band (13.8 GHz) and Ka band, has a great deal of similarity to the X- and Ka-band combination used on the aboard T-39 aircraft in terms of the general behavior of the DFR–D_0 relationship. As a consequence, our findings in this study have direct applications to estimation of snow in mid and high-latitude regions. It is anticipated that the GPM radar will play an important role in mapping the microphysical properties of hydrometeors globally.